IMPACT & MITIGATION STRATEGY OF IONOSPHERIC EFFECTS IN THE CONTEXT OF LOW FREQUENCY (L- / P-BAND) SAR MISSION SCENARIOS

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ABSTRACT

Currently, different low frequency spaceborne SAR missions are investigated by different agencies with respect to global vegetation mapping. The investigated missions differ not only in the choice of the central frequency (e.g. L- or P-band) but also in terms of system specifications (e.g. system bandwidth), and mission acquisition scenario (e.g. repeat-pass time) and provide different observation spaces. In this paper we first provide an assessment of the ionospheric impact on the individual elements of the observation space of the different missions. Then we review of potential correction approaches (techniques and/or implementations). Assessment of the expected performance of each approach projected onto the individual mission scenarios.

Ionospheric Impact: Earth's ionosphere affects the polarised frequency-modulated band-limited pulses transmitted and received by a Synthetic Aperture Radar (SAR) in multiple ways:

- Large-scale ionospheric structures (the background ionosphere) can cause attenuation, absorption, shifts in phase and group velocity, as well as dispersion, refraction and rotation of the polarisation of the transmitted/scattered radar pulse. The background ionosphere can be widely characterised by the Total Electron Content (TEC) and its large-scale spatial variability.
- Small-scale ionospheric structures, formed by electron density irregularities (the turbulent ionospheric) can cause random fluctuations in phase, amplitude and polarisation of the pulse signal, known as scintillation effects.

The magnitude of the ionospheric induced distortion depends on the central frequency (f_0), the system bandwidth (W) and the bandwidth-to-central-frequency ratio W/f_0 of the SAR. SAR systems operating at lower frequencies with large bandwidths are inherently more strongly affected by an active ionosphere. The distortion of the transmitted/scattered radar pulses introduces a number of errors on the processed SAR images which can be categorised into range, azimuth and temporal:

1. In range, the non-unity refractive index induces a delay (advance) of the group (phase) velocity corresponding to a time (phase) offset. At the same time, the frequency dependency of the refractive index leads to a spreading of the transmitted / received pulse that degrades the range resolution and defocuses the image.
2. In azimuth, the spatial variability of the background ionosphere across the orbit induces phase gradients: linear and quadratic terms are equivalent to a modified (and variable) frequency modulation due to a modified (and variable) Doppler frequency shift. A more severe form of distortion can be caused by electron density irregularities with spatial scale comparable to or less than the synthetic

aperture: the induced phase scintillations induce azimuth defocusing due to uncorrelated quadratic and higher order phase errors.

3. <u>In time:</u> non-compensated phase distortions in the interferometric images induced by the time-varying background and/or turbulent ionosphere cause differential phase distortions in the interferogram. The magnitude of the differential phase distortions depends on the magnitude of variation of the ionosphere from acquisition to acquisition.

Mitigation techniques and ionospheric correction scheme: The low central frequency combined with the available bandwidth and the systematic acquisition scenario makes the development of a dedicated ionospheric correction methodology necessary:

- Absolute range effects are of secondary importance for the intensity and polarimetric measurements. The absolute range correction depends on accurate knowledge of the orbit and the location of the scattering centre and can be performed locally on the basis of calibration (reference) targets. The spatial calibration accuracy depends then on the spatial variability of the active ionosphere.

- Dispersion effects, including range defocusing, are important at L-band where the realisation of up to 85MHz system bandwidth is possible according to the ITU-R regulations. On the other hand, at P-band dispersion effects can be neglected due to the very small system bandwidth (6 MHz due to ITU-R regulations) to central frequency ratio W/f_0. Accordingly, standard correction techniques based on dispersion effects become less effective at P-band than at L-band.

- The low central frequency makes dynamic ionospheric effects especially important. Scintillation effects have to be corrected on the basis of matched filter correction approaches. Furthermore, the temporal variation of large and small-scale ionisation structures is reflected into the interferometric measurements.

- Representative Faraday rotation angles for P-band are summarised in Table 1. Bearing in mind that for typical P-band forest measurements Faraday rotation of the order of 10° is sufficient to attenuate the co-polarised channels by up to 1 dB and amplify the cross-polarised channel by about the same level, it is clear that Faraday rotation must be corrected even for moderate ionospheric scenarios. Hence fully polarimetric data are essential as they facilitate the implementation of correction schemes (see, for example, Bickel & Bates, 1965; Freeman, 2004; Chen and Quegan, 2009).

Table 1: *Typical P-band Faraday rotation angles for different levels of solar activity (SA)*

(Wright et al., 2003)

	TEC [IN TECU; 1 TECU = 10^{16}ELECTRONS M^{-2}]		*ONE-WAY FARADAY ROTATION [DEG]*
	LOW SA	*HIGH SA*	
HIGH LATITUDES	***0.2-10***	***5-40***	***0-5 / 5-25***
MID-LATITUDES	***0.5-20***	***5-80***	***0-10/ 5-30***
LOW LATITUDES	***0.5-40***	***5-100***	***0-5 / 5-15***

Accordingly, successful ionospheric correction must account for Faraday rotation, mitigate scintillation and phase gradients in the range and/or azimuth direction and compensate for differential phase effects.

Phase scintillations can be distinguished into high frequency phase disturbances resulting from small-scale variations of the electron density and low frequency phase variations due to the finite ionosphere correlation interval. The most promising correction approaches are based on autofocus (AF) techniques (a brief review of such techniques is given in Oliver and Quegan, 1998); these are adaptive techniques that allow the estimation and/or compensation of second and/or higher order phase errors along the SAR integration path, thus improving image focus. Depending on the scene and the characteristics of the reference scatterers, the approach to implementing AF differs, as does its performance. There are three basic basic approaches:

1. AF implementations based on evaluating the phase history of individual deterministic scatterers. The high signal-to-noise ratio (SNR) and signal-to-clutter ratio (SCR) allow a more or less direct estimation of the phase error on each of these scatterers. Accordingly, this is the most efficient and direct AF approach, but is limited by the availability of dominant point-like scatterers.
2. For scatterers with moderate signal-to-noise ratio (SNR) and/or signal-to-clutter ratio (SCR), coherent AF techniques are applicable. In most cases they are based on range-compressed images and operate by varying the phase history (typically the linear FM rate coefficient) in azimuth to optimise certain image parameters. The Phase Gradient and Phase Difference approaches are of this type.
3. When the scatterers have low SNR and/or SCR, incoherent AF techniques are of advantage. They are based on the intensity of the final images (after compression in range and azimuth) and they completely ignore phase information. Representative approaches are Sub-Look Registration and Contrast Optimisation. Such methods are also useful for the moderate SNR and SCR case.

Note that AF techniques can be modified to account for absolute as well as differential phase distortions.

Faraday rotation compensation is usually linked to the availability of fully polarimetric SAR data. Several schemes have been proposed and successfully validated using quad-polarimetric data acquired by JAXA’s ALOS-PalSAR L-band satellite that has been in operation since 2007. Even though the performance of the individual compensation approaches varies, surprisingly high estimation accuracy was achieved, on the order of 1 degree (Meyer and Nicoll, 2008). Faraday rotation estimates are normally biased in low SNR areas and in the presence of system-induced distortion on transmit or receive (system cross-talk).

REFERENCES

1. Belcher, DP (2008) Theoretical limits on SAR imposed by the ionosphere, *IET Radar Sonar Navig*. **2**(6), 435–448.
2. S. H. Bickel and R. H. T. Bates, “Effects of magneto-ionic propagation on the polarization scattering matrix,” *Proc. IRE*, vol. 53, pp. 1089-1091, 1965.
3. Chen J and Quegan S (2009) Improved Estimators of Faraday rotation in spaceborne polarimetric SAR data, submitted to IEEE GRSL.
4. Freeman A (2004) Calibration of linearly polarized polarimetric SAR data subject to Faraday rotation. *IEEE Trans. Geosci. Remote Sens*., **42**, no. 8, 1617-1624.
5. Freeman, A., X.-Q. Pi and B. Chapman, “Calibration of PalSAR polarimetric data,” *Proc. POLinSAR* 2009, Frascati, Italy, Jan. 2009.
6. Li L and Li F (2003) SAR imaging degradation by ionospheric irregularities based on TFTPCF analysis. *IEEE Trans. Geosci. Remote Sens.*, **45**, no. 5, 1123-1130.
7. Meyer F. J. and Nicoll J.B.F., Prediction, Detection, and Correction of Faraday Rotation in Full-Polarimetric L-Band SAR Data, IEEE Transactions on Geoscience and Remote Sensing, vol. 46, no. 10, pp. 3076-3086, October 2008.
8. Oliver C J and Quegan S (1998) *Understanding synthetic aperture radar images*, Artech House.

9. Qi R.-Y. and Jin Y.-Q., Analysis of the effects of Faraday rotation on spaceborne polarimetric SAR observations at P-band, *IEEE Trans. Geosci. Remote Sens.*, vol. 45, no. 5, pp. 1115-1122, May 2007.
10. Snoeij, P.; van der Valk, N.; Boom, E.; Hoekman, D. (2001), Effect of the ionosphere on P-band spaceborne SAR images, *Geoscience and Remote Sensing Symposium, 2001 (IGARSS '01),* IEEE 2001 International, vol.1, pp.132-134,
11. Wright P, Quegan S, Wheadon N and Hall D (2003) Faraday rotation effects on L-band spaceborne SAR data. *IEEE Trans. Geosci. Remote Sens.*, **41**, no. 12, 2735-2744.